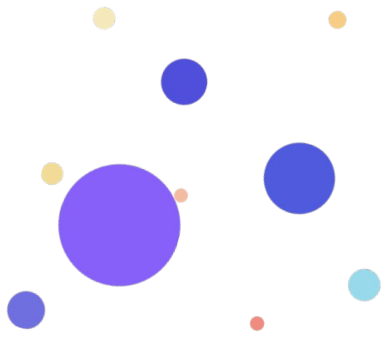
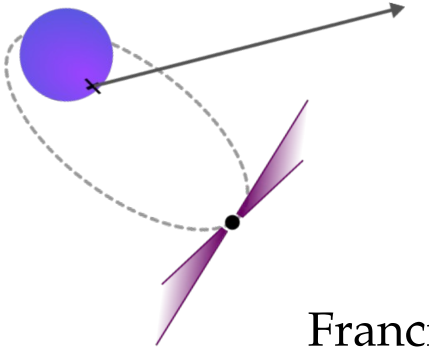
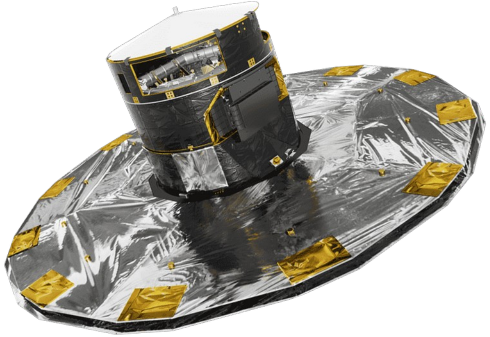
Finding the birthplace of High-Mass X-ray Binaries using Gaia EDR3 astrometry

Fortin, F., Garcia, F., Chaty, S., 2022A&A665..A69F







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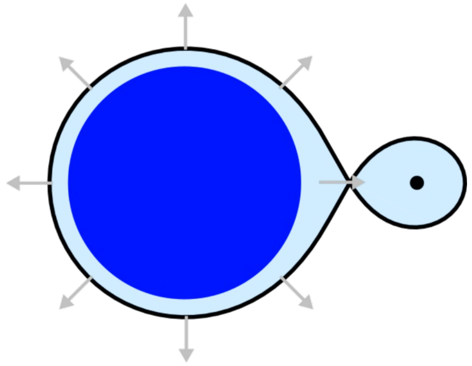
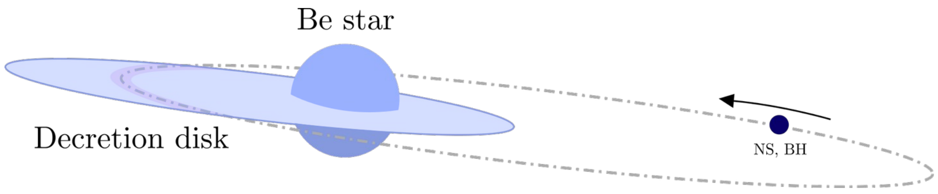
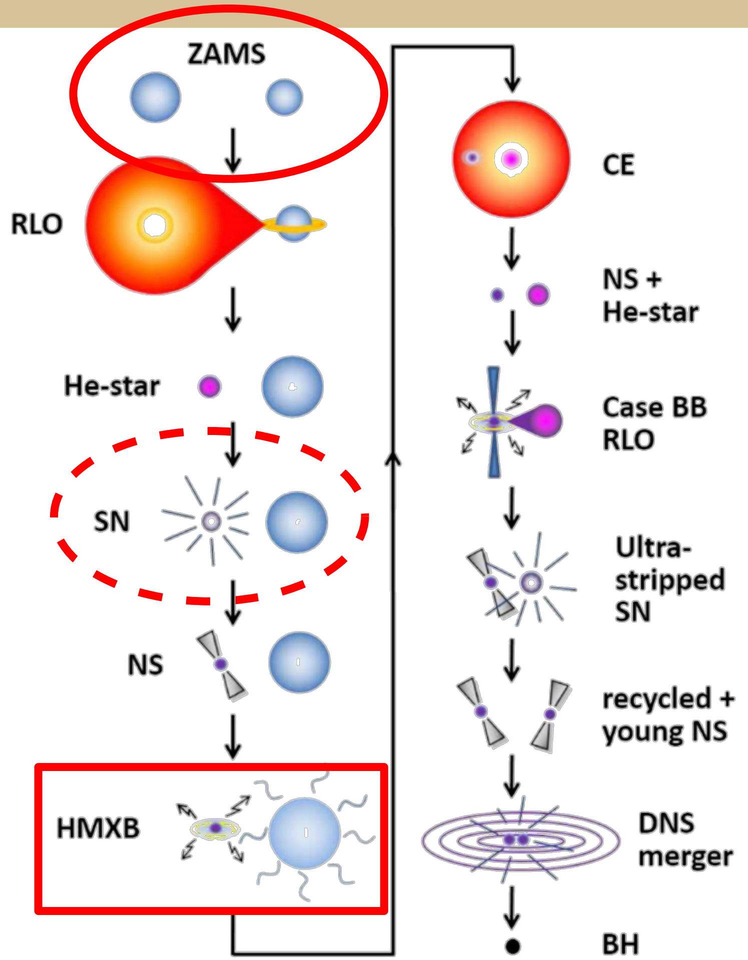
Evolution of High-Mass X-ray Binaries (HMXBs)



Wind Accretion

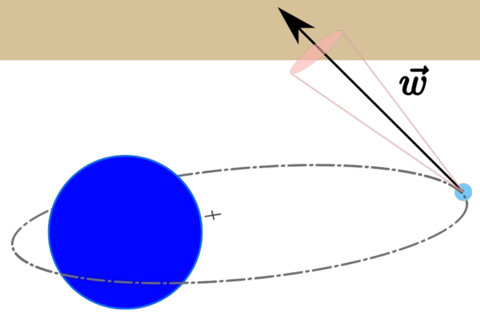


Decretion



Tauris+2017

Natal kick & migration from birth site



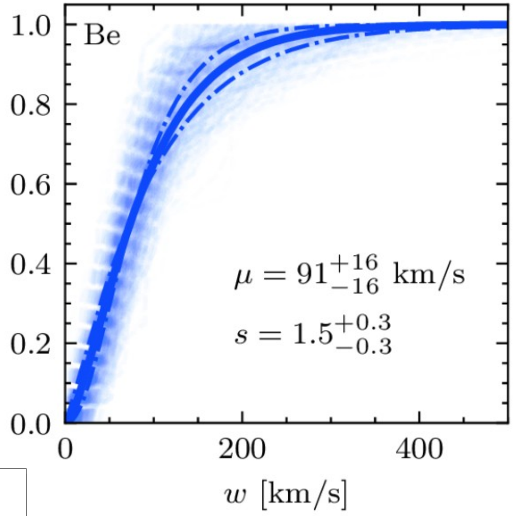
Supernova event = neutron star (or black hole) **natal kick.**

→ impact on orbital parameters (P_{orb}, eccentricity)

→ survivability (large kick → unbound system ?)

→ imprint on the peculiar velocity of the whole system

Order of magnitude : Vpec ~100 km/s → migration of ~ 100 pc/Myr



Fortin et al. 2022a

Even if HMXBs are young (few dozen Myr), migration distance can be high.

Birthplace of HMXBs and Galactic ecology

- Galactic structures susceptible of hosting massive star formation :

  young open clusters, spiral arms, isolated ?

Questions

How do HMXBs fit in the Galactic ecology ?

Are there correlations between formation scenarios and the nature of HMXBs ?

What we get

Infer the age of HMXBs since the first supernova event

→ evolution timescales, formation scenarios, history...

Correlation between spiral arms and/or OB associations in Milky Way : Bodaghee+2012, Coleiro+2013

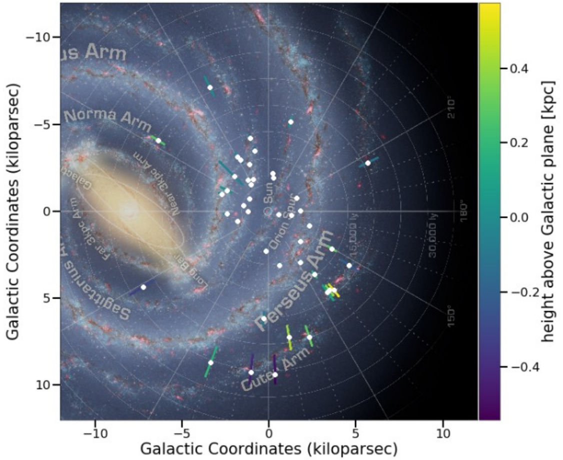
→ Need accurate kinematical data !

Astrometry from Gaia EDR3

High-Mass X-ray Binaries

Fortin+2022a

- 94 confirmed in Milky Way
- 80 observed by Gaia
- **26 with full 6-D astrometry**

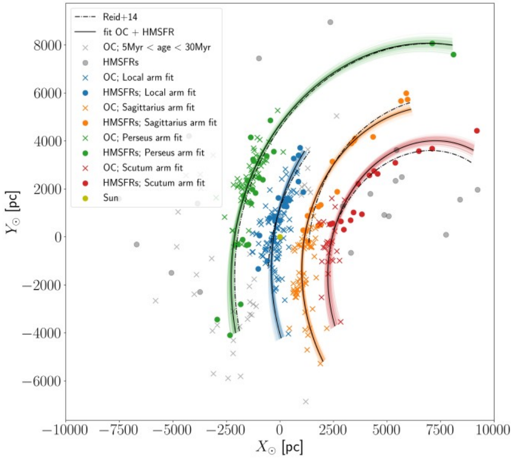


Galactic spiral arms

Castro-Ginard+2021

- Local, Sagittarius, Perseus, Scutum
- shape + motion

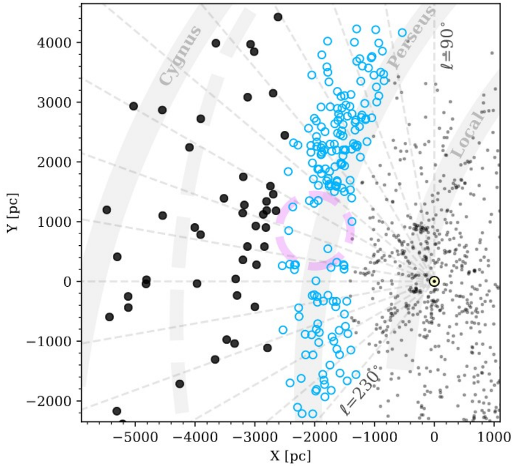
$$\ln \frac{R_G}{R_{G,ref}} = -(\theta_G - \theta_{G,ref}) \tan \psi$$



Open stellar clusters

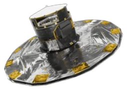
Cantat-Gaudin+2020

- 2017 within ~5kpc
- age from HR isochrone fitting
- **1381 with full 6-D astrometry**



Integration of orbit around the Milky Way

- Use of python module *Galpy* to initialize & integrate the motion of HMXBs and clusters
- MWPotential2014 (Bovy 2015) : bulge + disk + dark matter halo
- 500 timesteps of 0.2 Myr → explore the orbits until 100 Myr ago



Gaia astrometry is very accurate ! ... but not perfect :(

→ 1000 orbit integrations using initial parameters drawn from distributions according to Gaia data

- We obtain, for each timestep, a distribution of possible positions & velocities

→ Compute the possible distances to clusters and spiral arms to find **encounter candidates.**

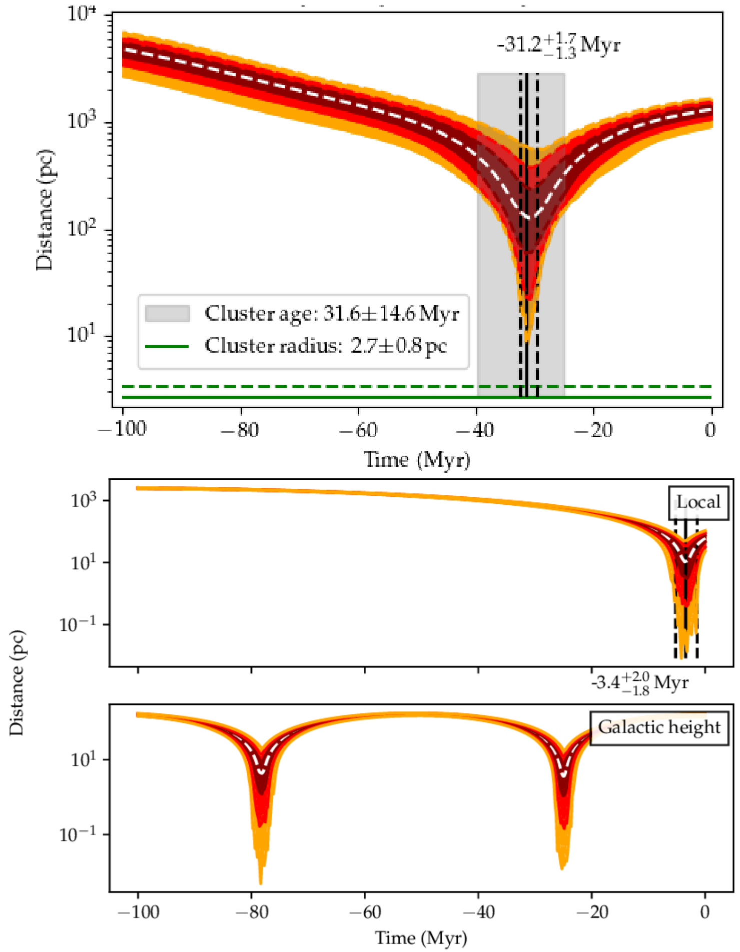
→ simple galactic potential, low sample size → not too CPU-intensive

Encounter detection : time-distance histograms

- Distance distributions represented by their median +/- 1, 2 and 3 sigma limits (84th, 97.7th and 99.8th percentiles)

- Convolution with the histograms depicting the radius of the clusters / width of the spiral arms (dependence with Galactic radius) + marginalize over time axis

→ A good encounter candidate produces a single peak in the marginalized data.

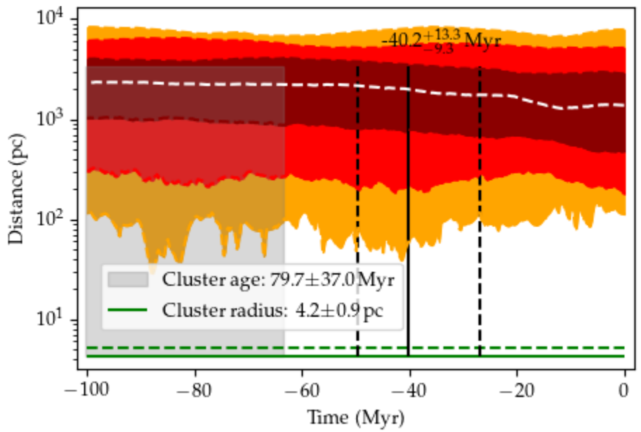


Encounter detection : validity of the method

→ Simulations over randomly generated HMXBs and clusters to test the ability to find a birthplace

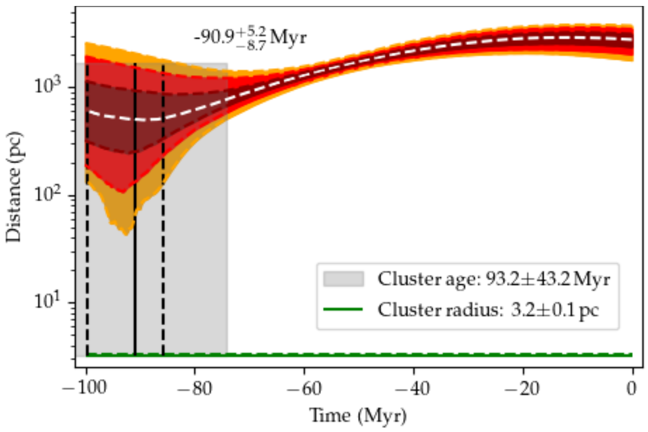
- chose a random birth date in [1 : 100] Myr
- initialize a birth cluster at a random position + velocity
- initialize HMXB born somewhere near the cluster
- apply random natal kick to HMXB
- integrate both orbits up until today
- generate dummy Gaia astrometry for HMXB & cluster of random quality (according to real data)
- look for an encounter

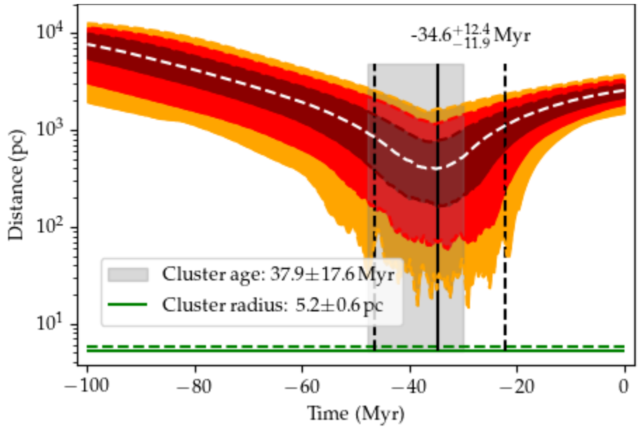
Encounter detection : validity of the method



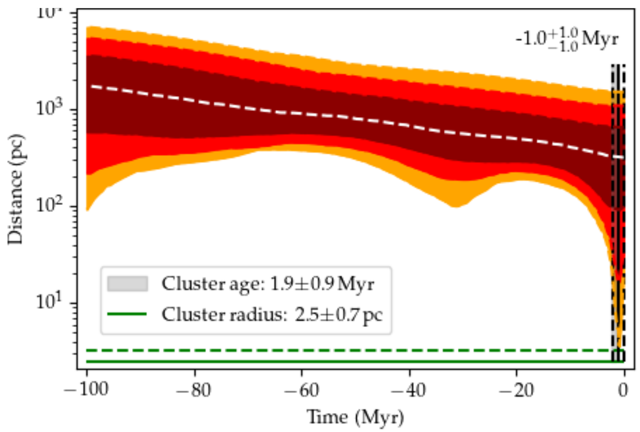
← Bad astrometry : 10% failed cases

Good astrometry →
retrieve old encounters





produce both sharp →
← and wide distributions



General results – Birthplace statistics

Open Cluster	tSN [Myr]
1A 0114+650	4.4
LS I+61 303	15
X Per	24
HD 259440	38
4U 1700-377	1.9
IGR J17544-2619	5.4
Cyg X-1	4.4

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Spiral arm	tSN [Myr]
1A 0535+262	18
2FGL J1019.0-5856	10
Cen X-3	1.9
1E 1145.1-6141	25
4U 1538-522	10
IGR J18450-0435	20
SS 433	<60
4U 2206+543	25

8

Isolated ?

IGR J00370+6122
IGR J08408-4503
Vela X-1
GX 301-2
PSR B1259-63
LS 5039
MWC 656

7

- HMXBs can have encounters with both clusters and spiral arms

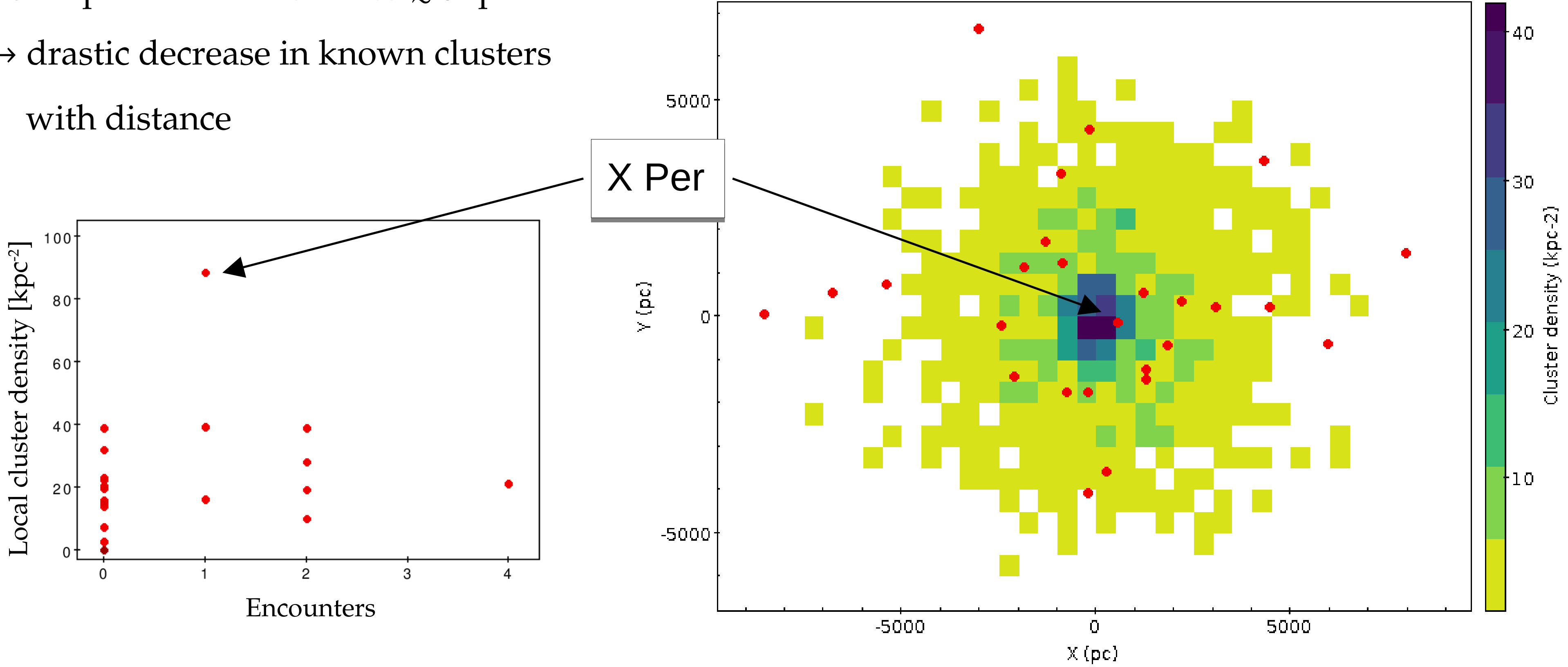
→ degeneracy is always lifted when taking into account companion mass & evolution timescales

Galactic distribution of Gaia clusters & HMXBs

- Gaia parallax → distances $\lesssim$ 5kpc

→ drastic decrease in known clusters

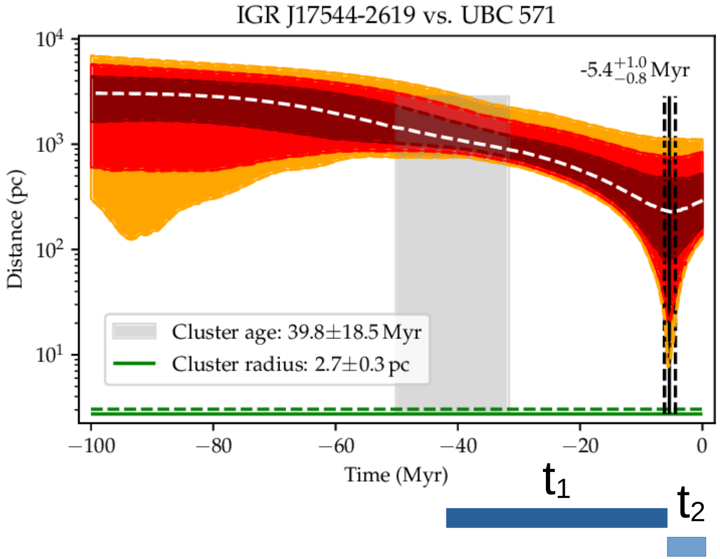
with distance



Extra results : ZAMS masses, and more

Mass – Age relation for massive stars (10 – 60 M⊙) : $\frac{M}{M_\odot} = \left[10^{-4}\left(\frac{t_{ZAMS}}{Myr}\right)\right]^{\frac{1}{1-\alpha}}$; $\alpha = 3.125$ (Figueiredo+1991)

Cluster encounters give primary star lifetime (**t_1**) and age since supernova (**t_2**) :



$t_1 \rightarrow M_{1,i} = 14.4 \pm 0.2\ M_\odot$	Primary ZAMS mass
$t_1 + t_2 \rightarrow M_{2,i} \leqslant 13.5 \pm 1.8\ M_\odot$	Secondary ZAMS mass (upper limit)
$M_{2,f} = 23\ M_\odot \rightarrow M_{acc} \geqslant 9.5\ M_\odot$	Initial mass transfer (lower limit)
$M_{1,\,pre\text{-}SN} \leqslant 4.9\ M_\odot$	Pre-supernova mass (upper limit)

→ Binary evolution through kinematics

Conclusion & Prospects

- propose birthplace for **22 HMXBs**, age since supernova for **15** and binary evolution history for **7**

→ done primarily using recent Gaia EDR3 on HMXBs, clusters and spiral arms

- no conflict between encounter candidates

- cluster / spiral arm / isolated formation : homogeneous, but likely biased towards spiral arms

- no perceptible trend among Be HMXBs, sg HMXBs, gamma-ray binaries, black hole binaries...

- Population synthesis & Galactic ecology: information on spatial distribution of HMXBs

- Binary evolution: constrained parameter space for hydrodynamical simulations (e.g. MESA)

- Currently observed HMXBs ↔ compact mergers ?

→ testing the knowledge on the impact of mass transfer, SN kicks, common envelope...

- **80** HMXBs observed by Gaia → only **26** with RV : we need more radial velocity (please !)

Thanks for your attention !